# The Hottest

## Scientists and engineers are exploring a new way to decontaminate soil at toxic waste sites by literally turning up the heat on pollutants.

By heating the ground using electricity or steam, contaminants are volatilized or otherwise mobilized so they can be removed from the ground and destroyed, or even destroyed in place. Among the targets for this method are solvents such as creosote, tetrachloroethylene, and trichloroethylene, many of which are known or reasonably anticipated to be human carcinogens, according to the National Toxicology Program.

While soils containing these contaminants can simply be dug up and carted off to landfills, that apparently cheap remedy is not without costs of another kind, says Ralph Baker, CEO and technology manager of TerraTherm, a firm specializing in environmental remediation and decontamination in Fitchburg, Massachusetts. "Excavation removes the source, but it is very intrusive," he says. "It tends to mean you are potentially exposing the community to contaminants that they don't want to [have] trucked through the area." Other concerns include the possibility of contaminants leaching into the environment and exposure to workers handling the contaminated soil.

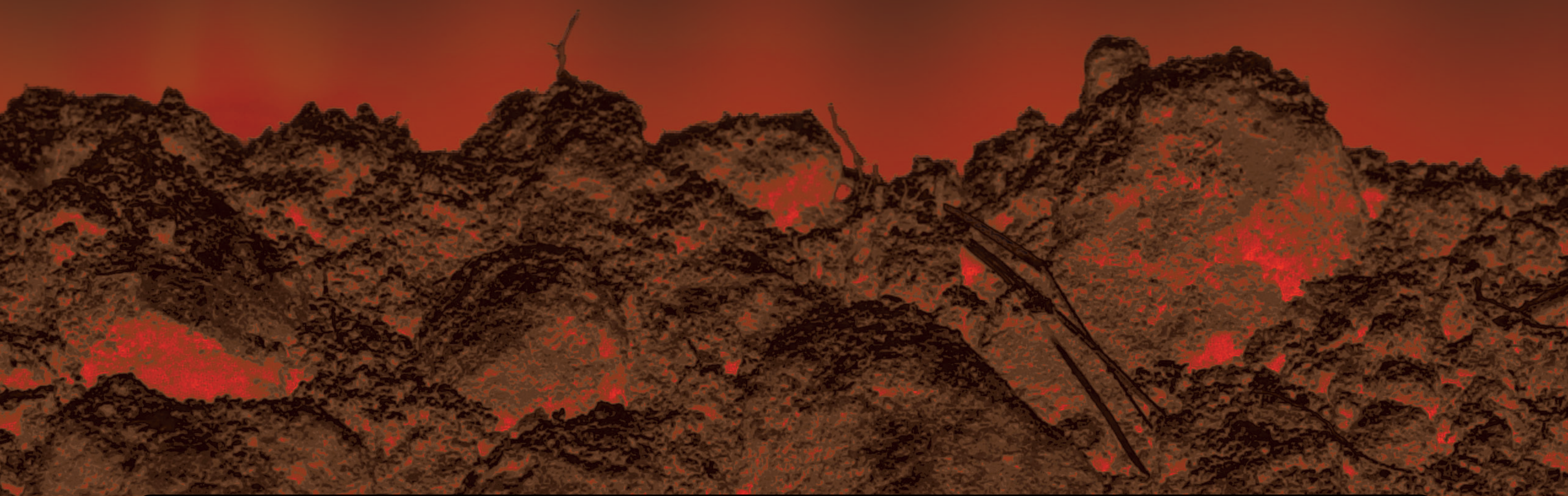
*In situ* thermal technologies avoid these problems. They also offer the potential to address contamination not previously amenable to cleanup at all, such as contamination at the depth of or beneath structures and contamination below the water table.

Roger Aines, a geochemist at Lawrence Livermore National Laboratory in Livermore, California, who helped develop the use of steam to decontaminate toxic waste sites, notes that steam has been used by oil companies to help extract oil from deep within the earth. And in the late 1980s, Shell Exploration and Recovery began to use electricity as a way to enhance oil recovery, Baker says.

The Shell researchers found that heating oil-containing geologic formations with electricity had a surprising effect. "They found the [underground] soil was like beach sand, it was so clean. They realized this might have application for environmental cleanup," says Baker, whose company

Arnold Greenwell/EHP, Christopher G. Reuther/EHP

# Thing in Remediation



uses this technology. "Almost every major technology that has been exploited for *in situ* remediation came out of the 'oil patch,'" he says. And such methods seem to be proving their value in ridding sites of toxic contamination.

## Electrifying Technology

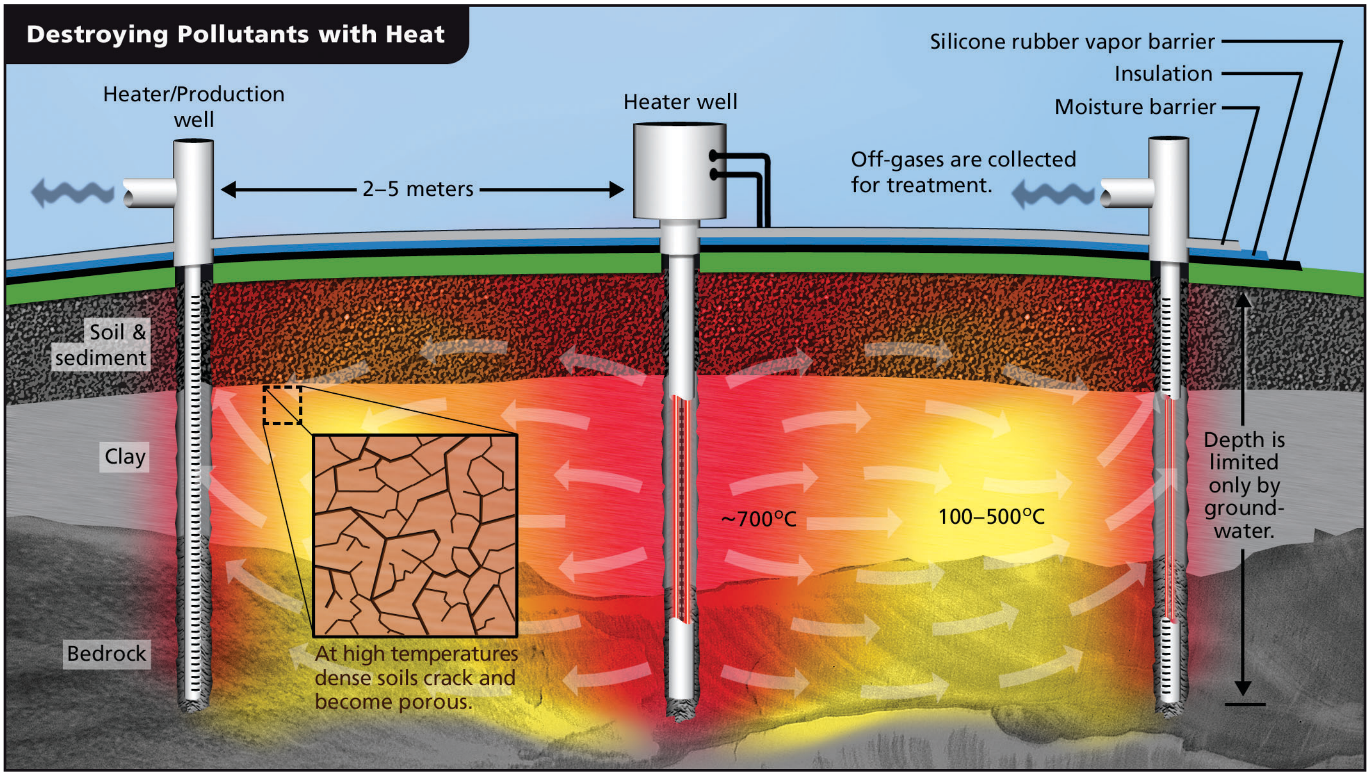
TerraTherm uses a technique called *in situ* thermal destruction in which the soil is heated to well beyond the boiling point of water using electrically powered heating elements. Baker says the elements are similar to those found in a toaster oven, and they heat target compounds enough that they burn. If burned in the absence of oxygen, only carbon is left. If oxygen is present, carbon dioxide and water are left.

The elements are contained inside pipes that are typically spaced 5–7 feet apart for a cleanup that will take 1–3 months. The heat flows 4–6 feet out from the heaters into the soil. For treating heavy contaminants with higher boiling points, such as heavy oils, the spacing would be closer. For lighter contaminants with lower boiling points, such as gasoline, the spacing would be farther apart.

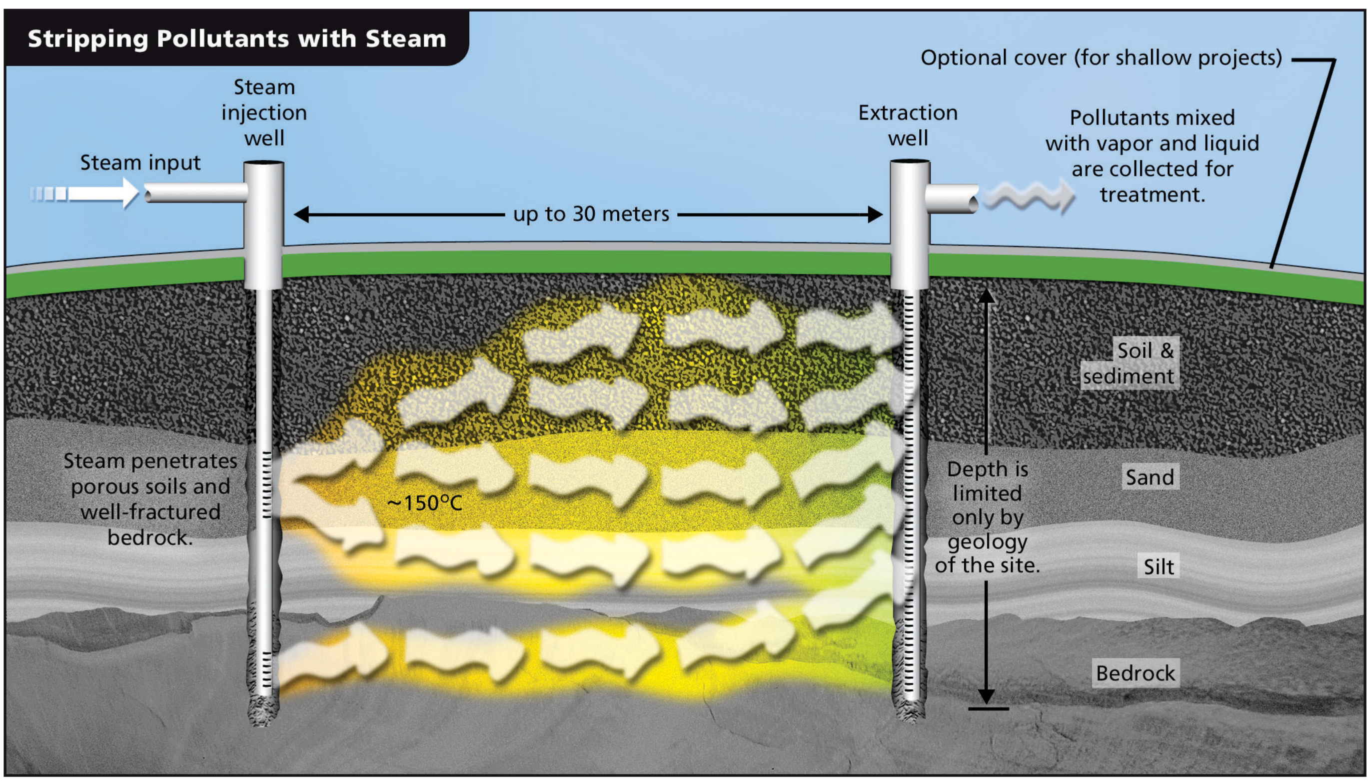
In 1997–1998, Shell used the technology on seven contaminated sites that contained a range of contaminants including polychlorinated biphenyls, chlorinated solvents, and diesel and gasoline fuel. Virtually all of the post-treatment confirmatory soil samples had no traces of contaminants, and just a few had minimal traces, Baker says.

Among TerraTherm's current projects is the cleanup of a 5,000-cubic-yard site in Lake Charles, Louisiana. Owned by Entergy Gulf States, the former manufactured gas plant is contaminated with tar. Other projects include cleaning up pesticide wastes on a 2,500-cubic-yard site at the Department of Defense's Rocky Mountain Arsenal near Denver, Colorado, and removing creosote from a 10,500-cubic-yard wood treatment site for the electric utility Southern California Edison near Los Angeles. All these projects are slated for 2002.

A second electric method, which also uses electrodes in the ground, is known as Six-Phase Heating™. Developed at Pacific Northwest National Laboratory in Richland, Washington, the process uses a transformer to split ordinary electric current into six different phases, or paths between electrodes. This creates a six-sided "web" of electricity that provides uniform heat throughout the section of earth to be cleaned, says William Heath, chief operating officer of Current Environmental Solutions of Richland, which uses this technique.




**Baked clean.** In soils such as clay that are too dense to penetrate with steam (below), *in situ* thermal destruction can be an effective remediation alternative. At a typical site, a central heater well is surrounded by six wells that contain heaters and vacuum mechanisms. The high temperatures produced by the heater array literally burn most pollutants out of the soil. Others are volatilized along with any moisture present in the soil. All the gases that result from this process are sucked toward the vacuum wells, where they can be collected and treated.




**Steam cleaning.** In porous soils, large polluted areas can be remediated with steam. In a typical dynamic underground stripping setup, injection wells force the steam into the ground, where it displaces or volatilizes pollutants, pushing them toward an extraction well. Because the process utilizes lower temperatures than *in situ* thermal destruction (above), fewer pollutants are destroyed in the soil. Rather, they are collected at the extraction well and further treated at the surface—for example, by controlled burning.

Christopher G. Reuther/EHP

Even heating is important, he says, because it ensures there will be no untreated spots.

The method successfully cleaned up soil contaminated with the solvents trichloroethane and trichloroethene at an electronics manufacturing facility in Skokie, Illinois, according to an October 1999 report by the U.S. Environmental Protection Agency (EPA) Technology Innovation Office titled *Cost and Performance Report: Six-Phase Heating™ (SPH) at a Former Manufacturing Facility, Skokie, Illinois*. The process ran from June 1998 through April 1999, with the exception of approximately a month between November and December. Describing the process as an "emerging technology," Heath says Six-Phase Heating has been used at about 15 sites around the country.

Jim Cummings, a technical expert in the Technology and Markets Program of the Technology Innovation Office, says electrical heating is particularly suited to sites with clay soils, which are not very permeable but have a higher water content than other soils and thus conduct electricity more effectively. In addition, he says, "heating generates steam, which causes expansion and, in the process of departing the clay matrix, results in dessication. This further contributes to contaminant recovery."

### Full-Steam-Ahead Cleanup

Steam is more effective in soils that are much more permeable. "The more permeable the medium, the more sand and gravel you have, [and] the better steam is going to work," says Aines. The steam-cleaning process, known as dynamic underground stripping, involves simply generating steam by using steam boilers and injecting the steam into the ground through pipes. The steam can then volatilize the contaminants and move them toward extraction wells that create a vacuum over the contaminants. The wells remove the volatilized contaminants and transfer them to aboveground facilities, where they are destroyed, says Norman Brown, vice president and chief scientific officer of Integrated Water Resources, a Santa Barbara, California, firm that uses the steam process under license from Lawrence Livermore National Laboratory. The system cools and condenses whatever material is recovered, and the waste is then burned in a controlled setting.

This method removed more than 1.3 million pounds of creosote from a four-acre Superfund site in Visalia, California, between June 1997 and November 1999. The site was a pole yard, where wooden utility poles had been treated with creosote to protect them from decay. Cummings notes that since 1976 the Visalia site had been the subject of "pump and treat" remedial activity, in which contaminated groundwater is brought to the surface and treated. Workers were recovering approximately 10 pounds of contamination each week. At that rate, given the amount that has since been recovered by steam injection, the utility company would have to have pumped and treated for over 3,000 years.

More recently, between September 2000 and September 2001, the steam process removed approximately 70,000 pounds of trichloroethylene and perchloroethylene from a site of 61,000 cubic yards at the Department of Energy's Savannah River Site in South Carolina. "That is more than twice the maximum estimate of contaminant that had been thought to exist [at the site]," says Brown. "On top of that, we know that some amount has been destroyed in place"—although he has no estimate of the amount destroyed in the ground.

### Bright Future for a Hot Commodity

The thermal technologies appear unexpectedly to have brought a natural ally into the cleanup process: thermophilic bacteria such as *Thermus* spp., common bacteria that thrive in high-heat environments. "We all used to think you basically sterilized the soil [with thermal remediation]," says Heath. "In reality, that's not true. We found that when we heat the soil, it wakes these [bacteria] up." The bacteria eat and digest contaminants, effectively destroying extremely difficult compounds that most other bacteria can't.

Although the major part of the work is done by the heat, these thermophilic bacteria may play an important role in achieving cleanup goals. Says EPA hydrologist Eva Davis, "There are likely to be small amounts of the contaminants remaining after thermal remediation, and the bugs that have been activated by the thermal processes can provide a 'polishing step' of getting the last little bit out of the soil. However, more research is neded to understand and optimize the relationship between the thermal and microbial processes."

Regardless of how significant a factor the bacteria are, heat treatments are likely to become an important remediation tool. Cummings estimates that 70% of Superfund sites have solvent contamination. And he says there are over 80 sites contaminated with the wood preservatives creosote and pentachlorophenol. Citing the Visalia project, he says, "We know that steam technology will work at wood treatment sites."

Many contaminated sites are in developed areas with subsurface structures such as gas, sewer, and electric lines and fiber optic cables. "People are concerned that by using thermal processes, you will damage fiber optic cables, telephone lines, that sort of thing," Cummings says. Although such damage has not happened, it is a possibility that those who use the technology should be aware of. This is not a technological limitation, he adds, but rather an engineering issue that would need to be addressed on a site-specific basis. He points to the successful use of Six-Phase Heating to restore the groundwater at a dry cleaner site located in a strip mall in Seattle. Restoration was achieved despite the significant presence of such structures, and all remediation equipment was placed below grade, thus eliminating possible interference with vehicular or pedestrian traffic.

Looking at thermal technologies in general, Brown, along with others in the field, is optimistic about their future. They have, he says, "potential to change the way we look at certain kinds of contaminated sites, particularly where there is a need for and goal to remove source mass of high concentration."

**Harvey Black**

## Suggested Reading

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